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THE INFLUENCE OF SUBJECT EXPECTATION ON VISUAL ACCOMMODATION IN THE DARK

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The prospect of a pilots vision at night being reduced to a less than optimal state by "night myopia" has been debated for years in a large body of research. This report casts doubt on the existence of night myopia in young healthy pilots by presenting evidence that the accommodative reflex may be driven by direct cognitive control inputs. Direct cognitive control, based on an individual's "expectation" of accommodative range, could bias *measures* of night myopia if the *measuring instruments* are placed close to the subject's eyes. Subjects studied for this report demonstrated excellent visual performance in the dark, at a range of 20 ft, despite "measured" night myopia of up to 7.94 diopters.

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SUMMARY PAGE

THE PROBLEM

Measurements indicate that most humans become myopic when presented with a visual field that is absent sufficient detail to stimulate focusing mechanisms (for example, in the dark). "Night myopia" averages about 2 diopters (focused at 50 cm) for the population as a whole. This suggests that a pilot flying in darkness or in an "empty field" such as an empty cloudy sky will be more likely to focus near the windscreen than at the optical infinity required for probable targets. In the past, experimental use of biofeedback techniques to circumvent this problem have appeared to be successful, but have been limited in practical application by expensive and cumbersome instrumentation.

A simple Scheiner-principle optometer was developed at the Naval Aerospace Medical Research Laboratory for self-evaluation of accommodative state, and biofeedback training to correct any deficits. This "pocket optometer"is hand held, light weight, and economical. It was designed to provide a cognitive feedback pathway to facilitate self-training. However, devices that provide feedback information to the subject are not usually suitable for scientific research because of possible bias in any resulting data. For this reason, a separate, vernier-type, optometer was also developed that provides no such feedback.

Previous studies carried out at the Naval Aerospace Medical Research Laboratory and elsewhere have shown great success in using the biofeedback paradigm to "train away" night myopia. Yet, one detail remains to be determined: Does subject *expectation* influence accommodative reflex? If so, then the literature that does not attempt to correct for this effect should be reconsidered. The experiments described in this report were designed to address this issue.

FINDINGS

The results presented here are preliminary due to the limited number (n=3) of subjects completing the study. All subjects were pilot candidates awaiting training at the Pensacola Naval Air Station, and all had excellent photopic vision. Unfortunately, when test screening indicated that night myopia was indeed present, 9 of 12 potential subjects (screened from 34) withdrew from the study. The generally given reason for withdrawal was fear of candidate disqualification for visual reasons, despite verbal and written assurances to the contrary. Night myopia measurements of the 3 subjects completing the study ranged from 1.48 to 5.43 diopters. All 3 subjects successfully eliminated their night myopia through training. Interestingly, however, *none of them* showed any real improvement in their visual capability in the dark, as measured by 3 simple tests: spot detection, stereopsis, and vernier acuity. This preliminary finding suggests that when night myopia is initially measured with a vernier optometer placed close to the subject's face, the subject's *expectation* of viewing something close drives his accommodative reflex. When, however, the subject attempts a visual task that is clearly at a distance, in the dark, his accommodative reflex reacts accordingly and appropriately. The fact that biofeedback training is easily accomplished strongly supports the idea of a viable cognitive control input to the accommodative system.

One could easily conclude from this study that the "problem of night myopia" is simply a non problem and go on to more productive endeavors. However, such a conjecture is not entirely satisfying when we remember the first description of night myopia by Maskelyne (1) in 1789. Maskelyne found that astronomical observations at night *were improved* by the addition of a minus correction lens. Why, then, was this improvement seen?

RECOMMENDATION

The suggestion that a subject's "expectation" can drive accommodation is based on a very small subject sample. More research with a larger number of subjects is needed to verify this finding.

INTRODUCTION

In 1789 Nevil Maskelyne, F.R.S., discovered and described the phenomenon we now call night myopia (1). Maskelyne found that astronomical observations at night were more accurate when a weak minus lens was added to his telescope eyepiece. Since Maskelyne's early description of the phenomenon, several theories have emerged to account for night myopia. The earliest theory, presented by Lord Rayleigh in 1883 (2), suggested that night myopia was caused by spherical aberrations in the eye that manifest themselves when the pupil widens. The outer zones of the eye are known to have greater optical power than the central region, and the pupillary response associated with decreasing light levels will expose more of the peripheral area. Elaborations of this hypothesis can be found in several sources (3-6). Spherical aberrations no doubt play a part in night myopia, but if they were significant then an experiment utilizing "artificial pupils" should cause an increase in myopia with an increase in pupil size. An artificial pupil is easy to implement. A thin metal plate with a hole of the appropriate size is placed in front of the eye. If the "artificial pupil" diameter is smaller than the subject's natural pupil then the smaller pupil effectively limits the light entering the eye to this smaller diameter. Hennessy *et al* (7) found that as pupil size was artificially decreased myopia *increased*. They reasoned that as pupil size decreases the optical depth of field increases, thus reducing the requirement for an accommodative reflex. When pupil size is reduced to 0.5 mm, measured myopia equals night myopia or the "resting state" of accommodation. Although many reports in the literature support the concept of a "resting state"(5,8-10), the experimental results vary (3-5,10-13) with some investigators supporting the concept and others rejecting it. Chromatic aberrations have also been suggested as a source of night myopia (5,14), but careful measurements of chromatic aberrations using monochromatic light suggest that only 0.3 to 0.4 diopters are present (10), although values as high as 0.75 diopters have been reported (4).

While spherical aberrations, chromatic aberrations, and accommodative reflex prevail as the major causative theories of night myopia, several other explanations have been suggested. For example, forward lens movement and increased lens sphericity may result from pupil dilation and increased vitreous pressure(15). Low light levels may give rise to an emptying of choroidal vasculature, thus causing recession of the retina (16). The distribution of cones predominates in the fovea, and cones are not sensitive to scotopic light levels. The subject may be employing off-axis viewing at low light levels(17). The periphery of the eye is dioptrically stronger than the central axis, so off-axis viewing could contribute to night myopia.

In all cases where experimental evidence is presented, the range of night myopia reported is quite large. Data collected at the Naval Aerospace Medical Research Laboratory from pilot candidates are unique in that all subjects are young, thus presumably possessing an agile accommodative reflex, and all subjects have excellent photopic vision. The data collected for this study have the widest range of night myopia reported in the literature, from +0.1 to -7.94 diopters. While spherical aberrations, chromatic aberrations and off-axis viewing all theoretically contribute to night myopia, they probably do not account for a range of almost 8 diopters, even taken all together.

The human accommodative reflex is generally assumed to be the result of a negative-feedback control loop, where de-focus somehow provides an error signal to drive accommodation in a corrective direction. Such control loops are ubiquitous in the human body (e.g., temperature regulation), and they are characterized by their ability to provide precise control of physiological phenomena in spite of any idiosyncratic features of the system components. The volume of research on biofeedback indicates that most of these systems can be cognitively influenced. Temperature control is a good example. Most individuals can learn to control the temperature on the back of their hand in a matter of minutes. Typically, a temperature probe is attached to the hand, and the subject is shown the readout. He is instructed to raise the value and, often to his surprise, he quickly finds that he can. The actual mechanism is presumably an increase in blood flow to the hand. This application of biofeedback has proved quite useful for individuals that suffer from migraine headaches to effectively reduce the blood flow in their cranium in favor of their hand, thus providing relief. The temperature measuring apparatus is merely an instrument to assist the individual to bring into consciousness control pathways that were there all along, but buried in the subconscious.

The human accommodative reflex is apparently akin to other physiological control loops in being under the influence of cognitition, albeit usually subconscious cognition. The success that we have been able to demonstrate at the Naval Aerospace Medical Research Laboratory (18) and that others have shown (19) with accommodative training supports this contention. If the subject can learn to control his accommodation cognitively, then the cognitive pathway must exist. The most probable inherent use of such cognitive circuitry is to place accommodation where the individual predicts his visual target to be. Such a predictive ability would have a positive selective value as it would improve reaction time. Unfortunately, however, the ability of an individual to direct his accommodation makes research in this field extremely difficult. Even though the instruments used to conduct the research may not directly drive the accommodative reflex in any way, the subject's *expectation* of accommodative distance may very well do so. In the case of laser Badal and vernier optometers, which are placed close to the individual when being used, the measured "night myopia" could merely be a measure of the subject's "judgement" about accommodative range. This phenomenon would help to explain the wide confusion in the published literature, but places a stringent restraint on the researcher who *must* design instrumentation to be physically located at near optical infinity (at least 20 feet). Otherwise, cognitive influences cannot be ruled out, and may be difficult to rule out even then.

METHOD

The experiment presented here is based on the premise that improving night myopia (by reducing it) should also improve night vision, if, indeed, night myopia actually exists in a form that is independent of the instruments used to measure it. Subjects were screened for night myopia using a vernier optometer. When night myopia was found and it exceeded 1.5 diopters, subjects were invited to participate in a training procedure to correct their night myopia. Those that accepted were administered 3 vision tests with stimuli physically located at 20 ft (to their certain knowledge) and presented in the dark after 45 min of dark adaptation. All of the tests used an up-down staircase, two-interval forced-choice paradigm with nine reversals, to determine threshold for detection. Data from the first two reversals were discarded as practice data. First, a "spot detection test" was given, where the light from a red light emitting diode (LED) was attenuated with a rotating neutral density wedge under computer control. Another, identical, neutral density wedge was placed in the light path with the "slope" reversed to compensate for the slope of the first wedge. Second, a stereopsis test was given by moving the relative position of two yellow LEDs together or apart and presenting them in the two intervals. Two tests were given: 1) the left light came forward and was compared to an exact match, and 2) the right light came forward and was compared to an exact match. Finally, the subject performed a "vernier acuity" task in an arrangement that simulated a Landing Aid Optical System as seen from one eighth mile. Again, two tests were given: 1) the "meatball" was raised above the aligned position and compared, and 2) the "meatball" was dropped lower than the aligned position and compared. Once baseline data were obtained a training paradigm was initiated using the "pocket optometer" described below, and it continued until night myopia was reduced essentially to zero as measured by the vernier optometer. After training, the above 3 tests were repeated to determine the effect of training.

THE VERNIER OPTOMETER

Screening for night myopia was done with a vernier optometer that has been described elsewhere (20,21). See Fig. 1 for a sketch of the vernier optometer. The primary reason for making the design shown in Fig. 1 was to address the following issues. First, chromatic aberrations in the eye force the use of monochromatic light in the measuring device to assure consistency. Second, because the dioptric power of the eye varies with eccentricity, a means of enhancing visual axis alignment was incorporated into the design. Referring now to Fig. 1, the subject, 1, uses the optometer by viewing two vertical yellow bars seen superposed on the background by a cube-type beam-splitter. The subject will also see a hazy red "bulls eye" at the intersection of the yellow bars if his eye is located such that the visual axis is in alignment with the axis of the optometer as viewed through the beam-splitter. The subject must cause the yellow bars to align vertically by moving the carriage, **18**, back and forth by means of a rack and pinion gear, **19**. Movement of the carriage, **18**, causes the distance an illuminated slit, **12**, is from a Badal lens, **11**, to vary. The image of the slit is polarized vertically at the bottom and horizontally at the top. Two pinhole apertures located horizontally in plate **3** are also covered with crossed polarizers, causing the light from the bottom half of the slit, **12**, to exit one pinhole, and light from the top half to exit the other. Movement of the relative position of the slit causes convergence or divergence of the two light bundles from the pinholes, causing their images (of the slit halves) to be diverged horizontally on the retina in proportion to the accommodative state of the subject. When the two slit-images are aligned, however, the relative distance of the slit from the Badal lens is a direct function of the accommodative state of the subject's eye.

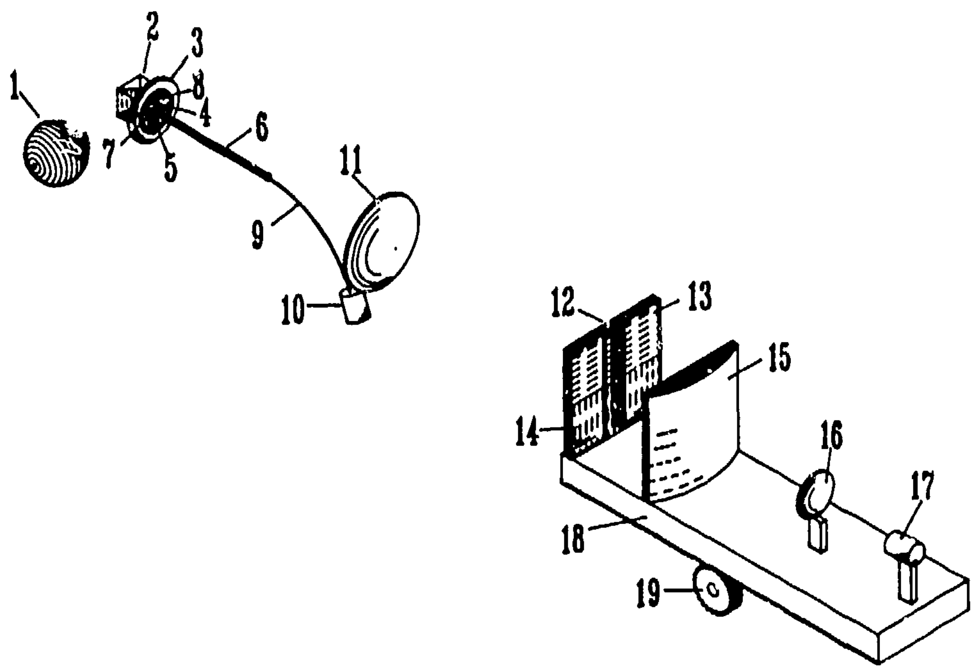

Figure 1. Sketch of a vernier optometer showing **1**, subjects eye; **2**, beam-splitter; **3**, aperture plate; **4** & **5**, pin holes; **6**, internal reflection tube; **7**, vertical polarizer; **8**, horizontal polarizer; **9**, fiber optic light guide; **10**, red LED; **11**, Badal lens; **12**, slit; **13**, vertical polarizer; **14**, horizontal polarizer; **15**, cylinder lens; **16**, lens; **17**, yellow LED; **18**, carriage: and **19**, rack and pinion carriage drive.

The vernier optometer is further elaborated by equipping it with position sensing electronics and a digital readout calibrated in diopters placed so that the subject cannot see it.

THE POCKET OPTOMETER

Training was carried out with a "pocket" optometer (18,22), also developed at the Naval Aerospace Medical Research Laboratory. This optometer is depicted in Fig. 2 and operates as follows. The subject views an extended scale, 6, through a plate, 2, with two pinholes and a Badal lens, 5. The scale is made from a film negative with the scale lines transparent and is back-illuminated with a diffuser screen, 7, and a yellow LED, 8. The scale is arranged such that the wide horizontal line (as viewed by the subject) is located at one focal length of the Badal lens, and the tick marks vary in distance from the Badal lens by diopters and half diopters. The subject sees two images of the scale, one through each pinhole, but the images are displaced horizontally because of the horizontal placement of the pinholes. If the subject's eye is focused at infinity, then the light coming from the horizontal line on the scale will be exactly focused at the same retinal location by both pinholes, thus canceling any displacement. Light from above and below the horizontal line will, however, be displaced horizontally because it is not at the appropriate focal distance.

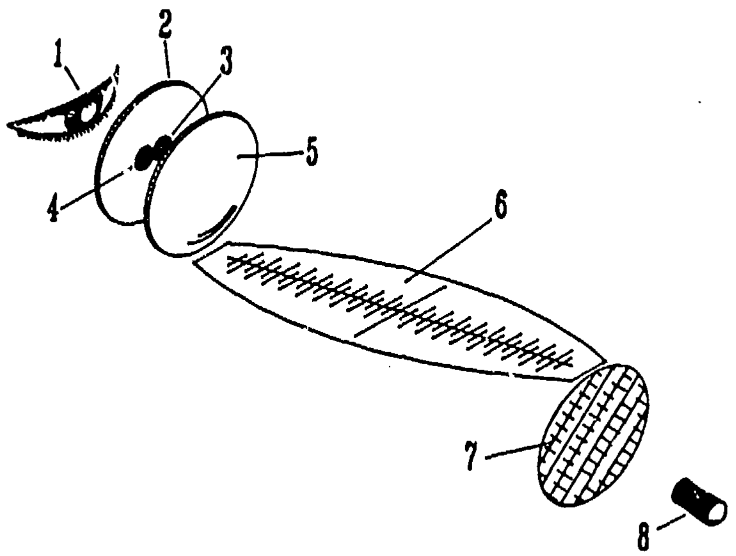

Figure 2. Sketch of a pocket optometer showing **1**, subject's eye; **2**, aperture plate; **3** & **4**, pin holes; **5**, Badal lens; **6**, scale; **7**, diffuser; **8**, yellow LED.

That is, displacement of the image on the subject's retina is a function of the distance of the image source along the scale and the dioptric power of the subject's eye. There is always, however, some distance on the scale for which the light exiting the pinholes is converged or diverged exactly the right amount to cancel the dioptric effect of the subject's eye, thus bringing the image from the two pinholes into alignment on the retina. This effect causes the subject to see something like the scales in Fig. 3. In Fig. 3, the leftmost crossed scale indicates a focus at optical infinity, or emetropia. Note that the apparent intersection of the scales coincides with the wide "horizon line." The middle view shows the view for a person with myopia. The intersection of the scales at 10 is roughly 4.5 tick-marks below the horizon line, corresponding to 4.5 diopters of myopia. The right-hand view indicates hyperopia.

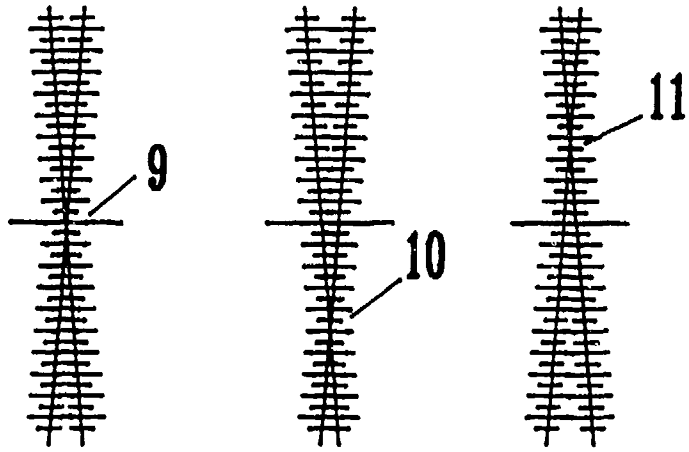

Figure 3. Three views through the pocket optometer showing **9**, emetropia; **10**, myopia; and **11**, hyperopea.

SUBJECT SCREENING

Subjects were screened using the vernier optometer. They were shown the device and allowed to align themselves with the image from the optometer using a chin and forehead rest. After the subject was settled, the lights were extinguished and the subject made 20 settings of the optometer by aligning the vertical bars. Between settings, the knob used to adjust the optometer was given a twist by the experimenter to decorrelate it. If the mean of the subject's settings was greater than 1.5 diopters of myopia, he was asked to participate in the study. Of 34 potential subjects, 12 had 1.5 diopters or greater of night myopia, and 3 agreed to participate in the study. The range of measurements for all 34 subjects was from 0.1 diopters of hyperopia to 7.94 diopters of myopia, with an overall mean of 1.73 diopters of myopia and a mean standard deviation of 0.39 diopters.

SUBJECT TRAINING

Subjects were trained by simply giving them access to a pocket optometer for no more than 1 h each day and allowing them to train themselves. The purpose of the training was explained, as was the meaning of the images they saw through the optometer. Most subjects reported very rapid initial control of their accommodation, often within seconds. However, control with feedback is one thing, without feedback is another thing altogether. At the end of each training session the subject was again tested with the vernier optometer to determine his progress, if any, and informed of the result. Fig. 4 shows typical results for one subject. The first trial is the pretraining screening and subsequent data points indicate the subject's training results after that particular day's work. Each data point is the mean and standard deviation for 20 measures of night myopia.

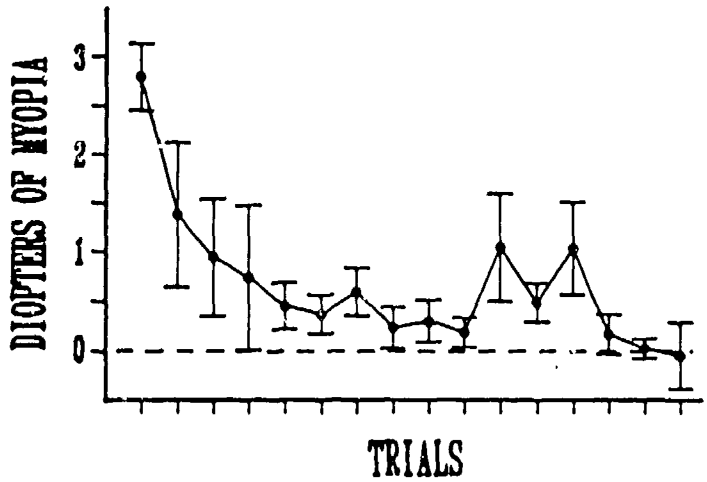

Figure 4. Typical training results for the pocket optometer. The first trial on the left is the pretraining screening result, and subsequent data points show consecutive results of daily training. All data points are means of 20 readings from a vernier optometer and error bars are standard deviations

RESULTS

The data shown in Table 1 are means and standard deviations of seven reversals of an up-down staircase for each point. Nine reversals were obtained in each case but the first two were discarded from the data as practice.

Table 1. Data from visual tests administered at 20 feet before and after biofeedback training for "night myopia" for 3 subjects.

	Subject #12 Initial, -5.43D (S.D. 1.09		Subject #13 Initial, -1.48 (S.D. 0.52)		Subject #15 Initial, -2.19 (S.D. 0.41)		Units
	Before Training	After Training	Before Training	After Training	Before Training	After Training	
Spot Detection							
Mean	0.0558	0.0653	0.0417	0.0417	0.0609	0.0424	Cd/m²
S.D.	0.0032	0.0034	0.0037	0.0037	0.0036	0.0037	Cd/m²
Stereopsis,Right Side Closer							
Mean	35.4	15.7	88.2	68.0	88.2	68.0	cm
S.D.	19.0	4.8	24.5	21.0	24.5	21.0	cm
Stereopsis,Left Side Closer							
Mean	30.7	18.1	76.9	87.6	76.9	87.6	cm
S.D.	23.0	9.5	20.4	28.9	20.4	28.9	cm
Landing Aid Optical System, Meatball Up							
Mean	3.5	4.6	2.0	2.4	2.5	1.9	minarc
S.D.	4.1	4.9	2.2	2.2	2.5	1.8	minarc
Landing Aid Optical System, Meatball Dn							
Mean	2.8	2.4	2.4	4.4	1.9	2.3	minarc
S.D.	2.8	2.8	2.2	4.7	1.8	2.5	minarc

DISCUSSION

Inspection of the data in Table 1 should convince the reader that there were no significant effects of training on any of the measures used; the differences between mean conditions did not exceed the standard deviations. This is not particularly surprising for the stereopsis and landing aid tests since it is not clear what cues may be used in performing these tasks. It *is*, however, surprising for the spot detection test. Defocus of a punctate light source causes the light from that source to be spread out on the retina in proportion to the magnitude of the defocus experienced. The intensity of the light is reduced by spreading and will fall below threshold at some point. This fundamental relationship between defocus and threshold can be demonstrated easily. On a starry night, observe some lesser stars with corrected vision and with, say, two diopters of defocus. The lesser stars that are plainly visible with good corrected vision will disappear with a small amount of defocus, in a fashion similar to what Maskelyne (1) reported over 200 years ago.

Subject #12 was initially tested with over 5 diopters of myopia, using the vernier optometer, yet when tested with targets at 20 feet he performed comparably with other subjects that tested with much less myopia. I must conclude, then, that even though subject #12 tested with substantial "night myopia" using the vernier optometer, it was the optometer itself that was driving that myopia, not an inherent characteristic of the subject. The vernier optometer was physically close to the subject, and the subject may very well have "expected" his accommodative range to also be close. The vernier optometer is in focus no matter where the subject accommodates, so, arguably, it does not itself drive the accommodative reflex. If actually present, 5 diopters of myopia would greatly handicap this subject taking vision tests at twenty feet.

We must remember that this discussion is based on very few subjects. If future research results in similar findings then the "problem of night myopia" may very well be a non problem --- at least for naval aviation candidates. This is not to say that "expectation" is the *only* source of night myopia, but, rather, probably one of many. Some individuals do have their night vision improved when they are corrected for night myopia (23).

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